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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : F01K 23/10	A1	(11) International Publication Number: WO 94/27034 (43) International Publication Date: 24 November 1994 (24.11.94)

(21) International Application Number: PCT/GB94/01013

(22) International Filing Date: 11 May 1994 (11.05.94)

(30) Priority Data:
9309735.0 12 May 1993 (12.05.93) GB

(71) Applicant *(for all designated States except US)*: BRITISH GAS PLC [GB/GB]; Rivermill House, 152 Grosvenor Road, London SW1V 3JL (GB).

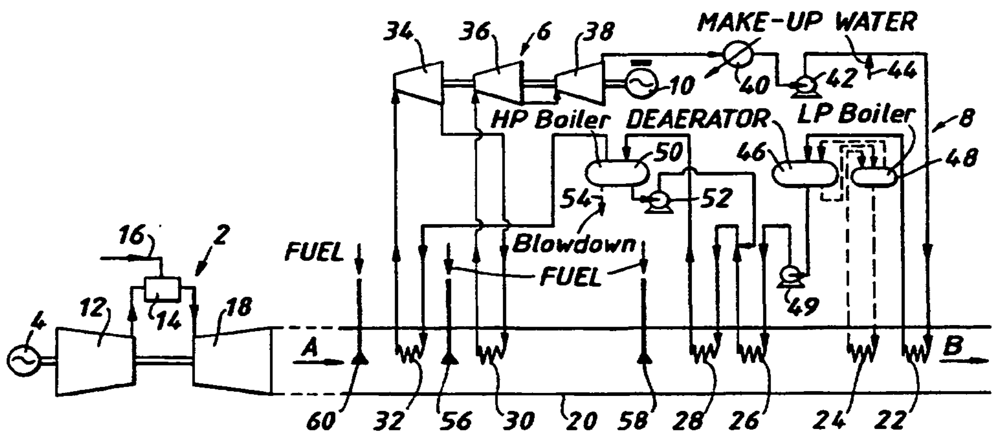
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: TIMMINS, Cyril [GB/GB]; 11 Whitehouse Close, Solihull, West Midlands B91 1SL (GB). SMITH, Keith [GB/GB]; 'Chadwick', Merlin Drive, Dalton in Furness, Cumbria LA15 8QE (GB). CHIM, Yuk, Tai [GB/GB]; 9 Redshank Court, Harrier Road, Hendon, London NW9 8B7 (GB). YUNG, Bruce, Pak, Keung [GB/GB]; 42 Rosemary Drive, Bromham, Bedfordshire MK43 8PP (GB).

(74) Agent: KINRADE, John; Intellectual Property Dept., British Gas plc, 59 Bryanston Street, London W1A 2AZ (GB).

(81) Designated States: AU, CN, HU, PL, RU, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: STEAM TURBINE



(57) Abstract

A steam turbine system comprises a steam turbine (6) driving electric generator (10), a heat recovering steam generator (8), and a gas turbine (2) driving electric generator (4). The steam generator (8) converts feed water into steam using heat exchanger coils (22, 24, 26, 28, 30 and 32) disposed at different places along a duct (20) carrying the hot exhaust gases from the gas turbine in directions A and B. Coil (22) is a boiler feed water heater, (24) a low pressure evaporator, (26) an economiser, (28) a high pressure evaporator, (30) a reheater, and (32) a superheater. The steam turbine has a high pressure cylinder (34), and intermediate pressure cylinder (36), and a low pressure cylinder (38). Superheater (32) supplies high pressure steam to the cylinder (34), reheater (30) supplies intermediate pressure steam to the cylinder (36) which supplies an output of low pressure steam to the cylinder (38). A fuel gas burner (56) is mounted in the duct between the superheater (32) and the reheater (30) to provide heat augmenting the heat in the exhaust gases. If desired another fuel gas burner (58) may be provided between the reheater (30) and the evaporator (28), and/or another fuel gas burner (60) may be provided between the gas turbine (2) and the superheater (32). The fuel gas can be natural gas which may power the gas turbine (2). The system can be used to generate electric power in a power station.

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STEAM TURBINE

This invention concerns a steam turbine in which heat is extracted from hot exhaust gases from a gas turbine, and the extracted heat used to heat steam to drive the steam turbine.

The invention is particularly, but not exclusively, applicable to combined cycle gas turbine (CCGT) electrical power generation.

A conventional CCGT power generation unit comprises a gas turbine which drives an electrical generator to produce electrical power. Hot exhaust gases from the gas turbine are ducted into a heat recovery steam generator (HRSG) and steam raised in the HRSG is supplied to a steam turbine which also drives an electrical generator to produce further electrical power. In this system the ratio of steam turbine power to gas turbine power is about 0.6.

In such a conventional system, steam conditions are restricted by the temperature of the exhaust gases from the turbine. For this reason it is not possible to utilise optimum steam conditions of high temperature and high pressure, so efficiency suffers. To compensate for this limitation large, modern CCGT units employ two or three pressure levels of steam raising (each level being raised in a separate boiler system) which adds considerable

complexity and cost to the unit. The largest and most modern CCGT units (one gas turbine and one steam turbine) can achieve electrical power outputs of up to 340MW at about 53% efficiency. It is known sometimes to provide a burner in the exhaust duct at a position therein between the gas turbine and the first part of any superheater arrangement encountered by the exhaust gases in the HRSG; the superheater arrangement being to heat high pressure steam for driving a high pressure cylinder of the steam turbine, and, in respect of the direction of exhaust gas flow along the duct, the burner being upstream of said first part of the superheater arrangement. The burner burns fluid fuel, for example fuel gas, and provides supplementary heat to increase steam production, but the amount of fuel used is relatively small compared with the amount used in the gas turbine. Supplementary firing in this manner is used mainly in combined heat and power plants to raise additional steam for process or heating use.

An object of the invention is to provide a steam turbine in which the need to raise steam at a multiplicity of pressure levels can be avoided, and in which steam at optimum conditions of high pressure and temperature can be raised in an HRSG using heat from exhaust gases from a gas turbine, the steam turbine comprising a first cylinder arrangement and a second cylinder arrangement, the first cylinder arrangement

being arranged to be driven by steam supplied thereto at a first pressure, the second cylinder arrangement being arranged to be driven by steam supplied thereto at a second pressure, the first pressure being greater than the second pressure, and the HRSG having a flexibility of heat input thereto enabling steam for driving the second cylinder arrangement to be produced to have a temperature and a second pressure which more closely approach an optimum for driving the second cylinder arrangement.

According to the invention a steam turbine comprises a first cylinder arrangement and a second cylinder arrangement,said first cylinder arrangement being provided to be driven by steam supplied to the first cylinder arrangement at higher pressure than steam supplied to said second cylinder arrangement to drive the second cylinder arrangement whereby said steam supplied to the second cylinder arrangement is at a lower pressure relative to said higher pressure, a superheater arrangement to heat the higher pressure steam to be supplied to said first cylinder arrangement, a reheater arrangement to heat the lower pressure steam to be supplied to said second cylinder arrangement and said reheater arrangement being arranged to receive steam from said first cylinder arrangement to be supplied as steam at said lower pressure to said second cylinder arrangement, said superheater arrangement comprising at least one

superheater heat exchanger in which the steam is to be heated, a gas turbine and passage means to convey away from the gas turbine hot exhaust gases, said superheater heat exchanger and said reheater heat exchanger being each disposed in said passage means to receive heat from said exhaust gases, and, with respect to the direction of flow of the exhaust gases along the passage means, said reheater heat exchanger being disposed downstream of the superheater heat exchanger, and heat source means being provided in said passage means downstream of the superheater heat exchanger and upstream of the reheater heat exchanger means for heat from said heat source means to augment the heat of the exhaust gases passing from the superheater heat exchanger to the reheater heat exchanger.

The heat source means may comprise burner means for burning fluid fuel.

Additional burner means may be provided in the passage means at a position or positions upstream and/or downstream of the first mentioned burner means.

The fluid fuel may be fuel gas.

The gas turbine and the steam turbine may drive respective electric power generators.

The invention will now be further described, by way of example, with reference to the accompanying drawings in which:-

Figure 1 is a diagrammatic representation of a

first embodiment of a steam turbine formed according to the invention;

Figure 2 is a diagrammatic representation of a variation of a part of the embodiment shown in Figure 1;

Figure 3 is a diagrammatic representation of part of a second embodiment of a steam turbine formed according to the invention, and

Figure 4 is a diagrammatic representation of part of a third embodiment of a steam turbine formed according to the invention.

In the drawings the same references identify the same or comparable parts.

Figure 1 illustrates a combined cycle gas turbine (CCGT) in which a gas turbine 2 drives an electric power generator 4, and a steam turbine 6, driven by steam raised in a heat recovery steam generator (HRSG) 8, drives an electric power generator 10.

Gas turbine 2 comprises an air compressor 12, a combustion chamber 14 supplied with fluid fuel by a supply 16, and a turbine section 18 from which the hot exhaust gases leave along the direction of arrow A and flow along a passage or duct to leave in the direction of arrow B, ultimately to atmosphere. If desired the generator 4 can be driven by drive taken off from the other end of the gas turbine 2 i.e. the end comprising the turbine section 18.

Various tubular coils or heat exchangers 22, 24, 26, 28, 30 and 32 of the heat recovery steam generator 8 are mounted in the duct 20 to receive heat from the hot exhaust gases from the gas turbine 2 to heat water and steam in the heat recovery steam generator to drive the steam turbine 6 which comprises a high pressure cylinder arrangement 34 to be driven by steam at high pressure, an intermediate pressure cylinder arrangement 36 to be driven by intermediate pressure steam, and a low pressure cylinder arrangement 38 to be driven by steam at low pressure. In the context of the steam turbine art the expressions "high pressure steam", "intermediate pressure steam", and "low pressure steam" are well understood by those skilled in the art.

In the heat recovery steam generator 8, steam exhausting from the low pressure cylinder arrangement 38 passes to a condenser 40 and the resultant water is pumped along the system by a pump 42. Downstream of the pump 42 make-up water may be added through a water supply 44 to compensate for water or steam loss. Then the water passes through a boiler feed water heater 22 and is supplied to a deaerator 46 comprising in known manner a heat exchanger (not shown) supplied with low pressure steam from a low pressure boiler or low pressure steam and water drum 48 from which water is converted into steam in a low pressure evaporator 24.

From the deaerator 46 the boiler feed water is

pumped by a pump 49 to an economiser 26 and passes to be converted to steam in a high pressure evaporator 28. The steam and any liquid water therein passes to a high pressure boiler or high pressure steam and water drum 50 (known per se) which has known means for monitoring a predetermined water level in the drum 50. A pump 52 is used to recirculate water from drum 50 to the inlet side of the high pressure evaporator 28. The drum 50 also includes a blowdown valve and outlet 54.

Steam from the drum 50 circulates through a superheater 32 and passes as high pressure steam to drive the high pressure cylinder arrangement 34 of the steam turbine 6. From the high pressure cylinder arrangement 34 the steam passes through a reheater 30. The steam leaves the reheater 30 at an intermediate pressure to drive the intermediate cylinder 36. From there the steam at low pressure is used to drive the low pressure cylinder arrangement 38 and then passes on to the condenser 40.

After the exhaust gases from the gas turbine 2 have passed the superheater 32 and given up heat thereto they become cooler. To inject further heat into the exhaust gases, to ensure that the exhaust gases impart sufficient heat to the reheater 30 to ensure that its intermediate pressure steam output is at a desired pressure and a desired temperature, at least one burner 56 arranged to be supplied with fluid

fuel is mounted in the duct 20 in a position between the superheater 32 and the reheater 30. Thus with respect to the exhaust gas flow direction A, the burner 56 is upstream of the reheater 30 and downstream of the superheater 32.

At least one other fluid fuel burner 58 is provided in the duct 20 between the reheater 30 and the high pressure evaporator 28 to inject further heat into the gas turbine exhaust gases to ensure enough heat is imparted to at least the high pressure evaporator 28 to raise the steam supplied to the drum 50 to a desired temperature to improve the chances of the steam from the superheater 32 and reheater 30 having the desired characteristics of temperature and pressure to drive the steam turbine in the desired manner.

At least one further fluid fuel burner 60 can be provided in the duct 20 between the gas turbine 6 and the superheater 32. The burner 60 may be used to inject heat into the exhaust gases to ensure that the high pressure steam generated has the desired characteristics of temperature and pressure to substantially match the design requirements of the steam turbine 6. But the amount of heat needed to be supplied by the burner 60 will usually be small if it is required at all. For example, the temperature of the exhaust gases leaving the gas turbine 2 may be of the order of 540°C and it may be desired to raise the

steam in the superheater 32 to a temperature of substantially 538°C, which is somewhat close to the exhaust temperature. So allowing for some heat losses in the duct the temperature of the exhaust gases at the superheater 32 may not be quite sufficient to ensure that the high pressure steam temperature has the desired value. Therefore it may be necessary to use the burner 60 to provide a small amount of "top-up" heat.

After the exhaust gases have passed the superheater 32 and are about to reach the reheater 30 the temperature drop in the exhaust gases may be of the order of 100° or 200°C. If it is desired that the temperature of the intermediate pressure from the reheater also have a temperature of 538°C, the provision of the burner 56 is a necessity to ensure that enough heat be injected into the exhaust gases to ensure that the reheater 30 is at the appropriate desired temperature.

The burner 58 can be used to impart heat to the exhaust gases passing the high pressure evaporator 28 and the economiser 26 to meet their heat requirements so as to produce steam at a temperature and pressure which are sufficiently high to ensure that the step-up to the high pressure and temperature desired for the steam output from the superheater 32 can be attained at the superheater.

The system in Figure 1 may be designed to give

a steam turbine electrical power output to gas turbine electrical power output ratio of substantially 1.0, with steam leaving the superheater 32 at a pressure of substantially 165 bar and a temperature of substantially 538°C and the steam leaving the reheater 30 at a temperature of substantially 538°C.

The temperatures in the duct 20 are not excessive, for example below 700°C. Thus a relatively inexpensive heat withstanding duct 20 can be used, because the cost of high temperature resistant materials for the duct need not be incurred. If, for example,only the burner 60 were present, it would be necessary to raise the temperature of the gas turbine exhaust gases at the burner 60 and superheater 32 to some hundreds of degrees Celsius above the temperature of the exhaust gases leaving the gas turbine 2. That is because it is desirable to ensure that the exhaust gases are still sufficiently hot when they reach the reheater 30 (and preferably the high pressure evaporator 28 and economiser 26). Thus in the region of the burner 60 and superheater 32 the duct would have to be made from very high temperature resistant material. But because the burner 56 is present it is only required to raise the temperature of the exhaust gases to a value sufficient to meet the needs of the reheater 30, which are not excessively high, e.g. below 700°C and when the burner 58 is present it too does not need to raise the temperature of the exhaust

gases to an excessive value to match the heating needs of the high pressure evaporator 28 or the economiser 26.

In the variation shown in Figure 2, the boiler feed water heater 22 in Figure 1 is omitted. Instead, boiler feed water is initially heated by one or more preheaters 62 each comprising a heat exchanger in which the water is heated by heat transferred thereto from steam taken off from either or both the intermediate pressure cylinder arrangement 36 and the low pressure cylinder arrangement 38 and after the preheater(s) sent to the deaerator 46 via pipe 64.

In the embodiment in Figure 3, the high pressure evaporator arrangement 28 comprises, in relation to the direction of exhaust gases flow A, a downstream high pressure evaporator 28a and in parallel therewith an upstream high pressure evaporator 28b, with the burner 58 disposed between them. The superheater arrangement 32 comprises a downstream superheater 32a and in series therewith an upstream superheater 32b. The downstream superheater 32a is downstream of the reheater 30 and upstream of the upstream evaporator 28b. At least one fourth fluid fuel burner 66 is disposed in the duct between the reheater 30 and the downstream superheater 32a. Again the maximum duct temperature can be maintained below 700°C, the burner 66 imparting heat to the exhaust gases to replace that extracted by the

reheater 30 and bring the temperature of the exhaust gases at the downstream superheater 32a up to a value meeting the requirements of the superheater 32a. The system in Figure 3 may be designed, due at least in part to the supplementary firing provided by the burner 66, to give a steam turbine electrical power output to gas turbine electrical power output ratio of substantially 1.5 with the steam leaving the upstream superheater 32b at a pressure of substantially 165 bar and a temperature of substantially 538°C and the steam leaving the reheater 30 at a temperature of substantially 538°C.

The embodiment shown in Figure 4 uses supercritical steam from the superheater arrangement 32 to drive the steam turbine 6. After the economiser 26 feed water at a pressure greater than a critical pressure of about 210 bar is passed through heat exchanger 68 disposed in the duct 20. That heat exchanger 68 forms a convective heater in which the water flashes into steam without the need of latent heat. This supercritical steam passes to a separator 70 in which water droplets carried over separate from the steam, and the separated water is returned to the deaerator 46.

The reheater arrangement comprises an intermediate pressure reheater 30a and a low pressure reheater 30b both at substantially the same position along the duct 20. Whilst reheater 30a heats steam

from the high pressure cylinder arrangement 34 and feeds it to the intermediate pressure cylinder arrangement 36, the low pressure reheater 30b heats steam from the intermediate pressure cylinder arrangement and feeds that steam to the low pressure cylinder arrangement 38.

Separator 70 supplies steam to the superheater arrangement 32 comprising the superheaters 32a and 32b in series, the downstream superheater 32a being downstream of the reheaters 30a and 30b, and the upstream superheater 32b being upstream of the reheaters, with the burner 56 being between the reheaters and the upstream superheater 32b.

The system in Figure 4 may be designed to give a steam turbine electrical power output to gas turbine electrical power output ratio of substantially 1.0, with steam leaving the upstream superheater 32b at a pressure of substantially 310 bar and at a temperature of substantially 566°C which is substantially the same temperature at which steam is supplied from each of the reheaters 30a and 30b.

The amount of air in the exhaust gases emerging from the gas turbine 6 may provide sufficient oxygen to support combustion of the fluid fuel at each of the burners 56, 58, 60 and 66 referred to above. Or if extra oxygen is required additional air may be introduced into the duct 20, for example in the vicinity of any of the burners, or air may be

pre-mixed with the fluid fuel supplied to any burner.

Because the burners use the oxygen in the exhaust gases, this provides a good possibility to minimise the formation of the oxides of nitrogen (NOx).Also the chance of NOx production is reduced because the operating temperatures in the duct 20 are not very high.

The fluid fuel referred to above supplied to the gas turbine 6 and each or any of the burners 56, 58, 60 or 66 may be a liquid fuel, or a fuel gas, for example natural gas.

The gas turbine 2 and the steam turbine 6 drive electric generators 4 and 10, as described above, which may generate electric power in a power station for transmission therefrom.

From the description of the embodiments above it will be appreciated that an existing steam turbine (say for example in an existing power station which may have originally been fired by coal or oil) having already defined operating steam characteristics can be adapted by substituting gas turbine exhaust gas firing as described for the original form of firing. Put simply, an existing steam turbine can have the combination of the gas turbine 2 and an above described heat recovery steam generator 8 (with at least burner 56) retrofitted to provide steam of the appropriate characteristics with which the steam turbine 10 was originally designed to work. From

the above disclosure it will be appreciated that the application of the invention overcomes many of the limitations of the conventional combined cycle gas turbine arrangement and provides:

- steam conditions which are independent of the gas turbine exhaust temperature,
- single or multiple steam heat as required,
- increased ratio of steam turbine to gas turbine electrical power output.

The ways in which the invention may be utilised as described above permits the selection of optimum steam conditions, including multiple reheat, for a wide variety of situations and give high efficiency without the need for a complex multiplicity of steam raising pressure levels. Application to the retrofitting to existing power stations may be particularly beneficial as the steam conditions required by the existing steam turbine can be met and thus full advantage taken of the performance the steam turbine was originally designed to attain. A range of possible steam generator arrangements have been investigated and the results suggest that any gas turbine can be matched with any required steam conditions and arrangement of steam circuits using the burner 56 and possibly one or more other burners firing at various locations along the gas turbine

exhaust gases duct.

CLAIMS

1. A steam turbine comprising a first cylinder arrangement and a second cylinder arrangement, said first cylinder arrangement being provided to be driven by steam supplied to the first cylinder arrangement at higher pressure than steam supplied to said second cylinder arrangement to drive the second cylinder arrangement whereby the said steam supplied to the second cylinder arrangement is at a lower pressure relative to said higher pressure, a superheater arrangement to heat the higher pressure steam to be supplied to said first cylinder arrangement, a reheater arrangement to heat the lower pressure steam to be supplied to said second cylinder arrangement and said reheater arrangement being arranged to receive steam from said first cylinder arrangement to be supplied as a steam at said lower pressure to said second cylinder arrangement, said superheater arrangement comprising at least one superheater heat exchanger in which the steam is to be heated, said reheater arrangement comprising at least one reheater heat exchanger in which the steam is to be heated, a gas turbine and passage means to convey away from the gas turbine hot exhaust gases, said superheater heat exchanger and said reheater heat exchanger being each disposed in said passage means to receive heat from

said exhaust gases, and with respect to the direction of flow of the exhaust gases in the passage means, said reheater heat exchanger being disposed downstream of the superheater heat exchanger, and heat source means being provided in said passage means downstream of the super heater heat exchanger and upstream of the reheater heat exchanger for heat from said heat source means to augment the heat of the exhaust gases passing from the superheater heat exchanger to the reheater heat exchanger.

2. A steam turbine as claimed in Claim 1, in which the heat source means comprises burner means for burning fluid fuel.

3. A steam turbine as claimed in Claim 1, in which in addition to said first mentioned burner means, one or more second burner means for burning fluid fuel is/are disposed in the passage means at a different position or positions along the passage means from the first mentioned burner means.

4. A steam turbine as claimed in Claim 1 or Claim 2, in which burner means for burning fluid fuel is provided in the passage means downstream of the said reheater heat exchanger and upstream of a high pressure evaporator heat exchanger.

5. A steam turbine as claimed in any of Claims 1, 2 or 4, in which burner means for burning fluid fuel is provided in the passage means upstream of the said superheater heat exchanger.

6. A steam turbine as claimed in any one of Claims 1, 2, 4 or 5, in which the superheater arrangement comprises said first mentioned superheater heat exchanger and at least a second superheater heat exchanger, said second superheater heat exchanger is disposed downstream of the reheater heat exchanger, and burner means for burning fluid fuel is provided in said passage means downstream of said reheater heat exchanger and upstream of said second superheater heat exchanger.

7. A steam turbine as claimed in any one of Claims 1, 2, 4, 5 or 6, in which the reheater arrangement comprises at least two reheater heat exchanges.

8. A steam turbine as claimed in any one of Claims 1 to 6, in which there is a third cylinder arrangement, and with respect to the steam pressures supplied to the cylinder arrangements, the first cylinder arrangement is supplied with high pressure steam by said superheater arrangement, the second cylinder arrangement is supplied with intermediate pressure steam from said reheater arrangement, and the third cylinder arrangement is supplied with low pressure steam, said intermediate pressure steam being at a pressure which is less than that of said high pressure steam and greater than that of said low pressure steam.

9. A steam turbine as claimed in Claim 7 and

Claim 8, in which said intermediate pressure steam is supplied from one of said reheater heat exchangers and said low pressure steam is supplied from another of said reheater heat exchangers.

10. A steam turbine as claimed in any one preceding Claim, in which the superheater arrangement is arranged to supply supercritical steam.

11. A steam turbine as claimed in any one preceding Claim, in which said cylinder arrangements were originally driven by steam generated by a steam generation system utilising heat provided from an originally provided heat generating means which is other than a gas turbine, and the gas turbine referred to in Claim 1 was installed later to replace said originally provided heat generating means.

12. A steam turbine as claimed in Claim 2 or Claim 3, or in any one of Claims 4 to 11 when appended to Claim 2, in which fluid fuel is supplied to the gas turbine, and said fluid fuel supplied to the gas turbine and/or to at least one of said burner means is liquid fuel.

13. A steam turbine as claimed in any one of Claims 1 to 12, in which fluid fuel is supplied to the gas turbine, and said fluid fuel supplied to the gas turbine and/or to at least one of said burner means in fuel gas.

14. A steam turbine as claimed in Claim 13, in which the fuel gas is natural gas.

15. A steam turbine as claimed in any one preceding claim, in which the cylinder arrangements provide a rotary power output driving an electrical power generator.

16. A steam turbine as claimed in any one preceding claim, in which the gas turbine provides a rotary power output driving an electrical power generator.

17. An electrical power station to generate electric power using a steam turbine as claimed in any one preceding claim.

18. Electric power generated by use of said steam turbine in the power station claimed in Claim 17.

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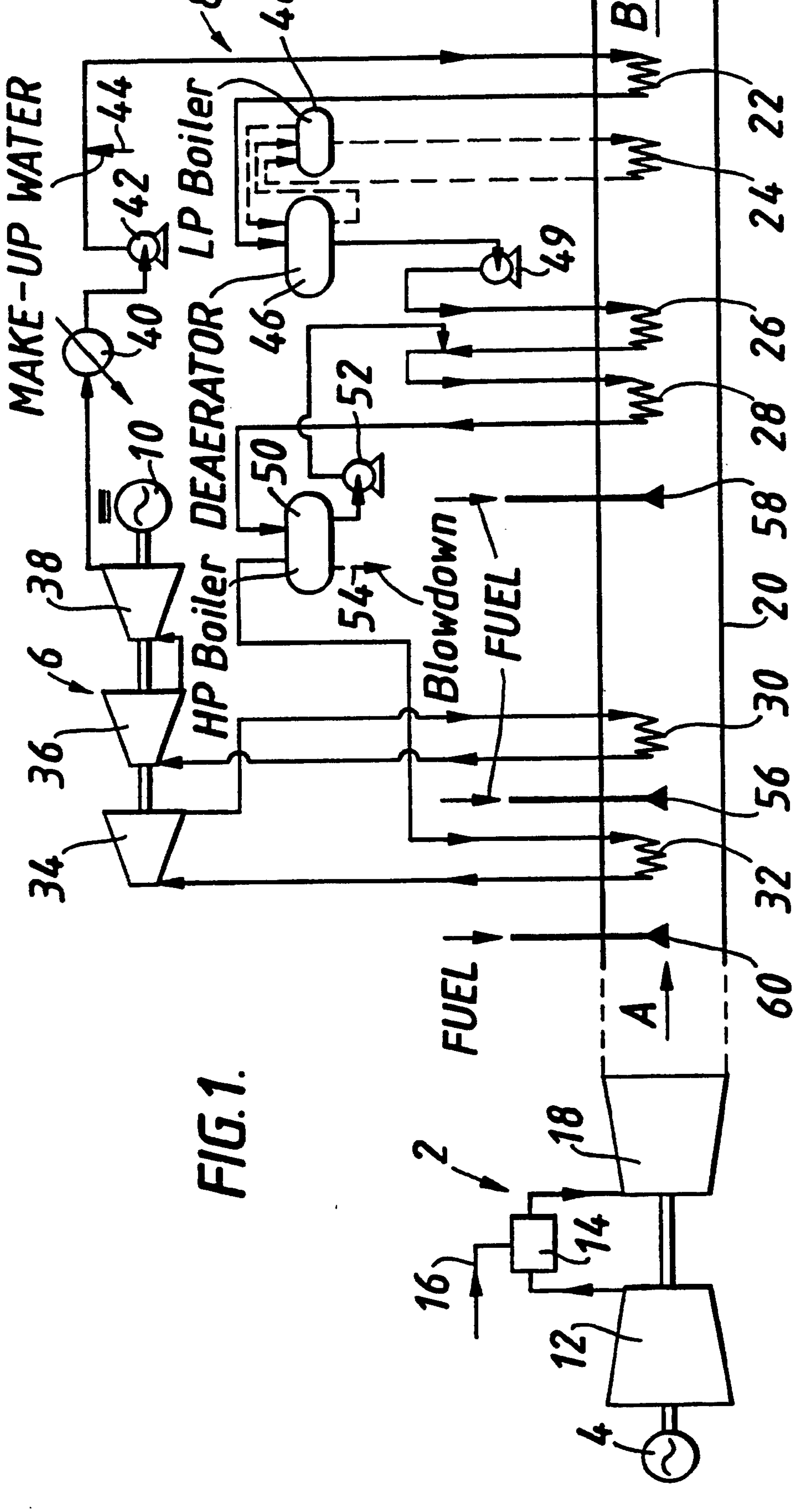
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LP Boiler
DEAERATOR
HP Boiler
Blowdown
FUEL
FUEL
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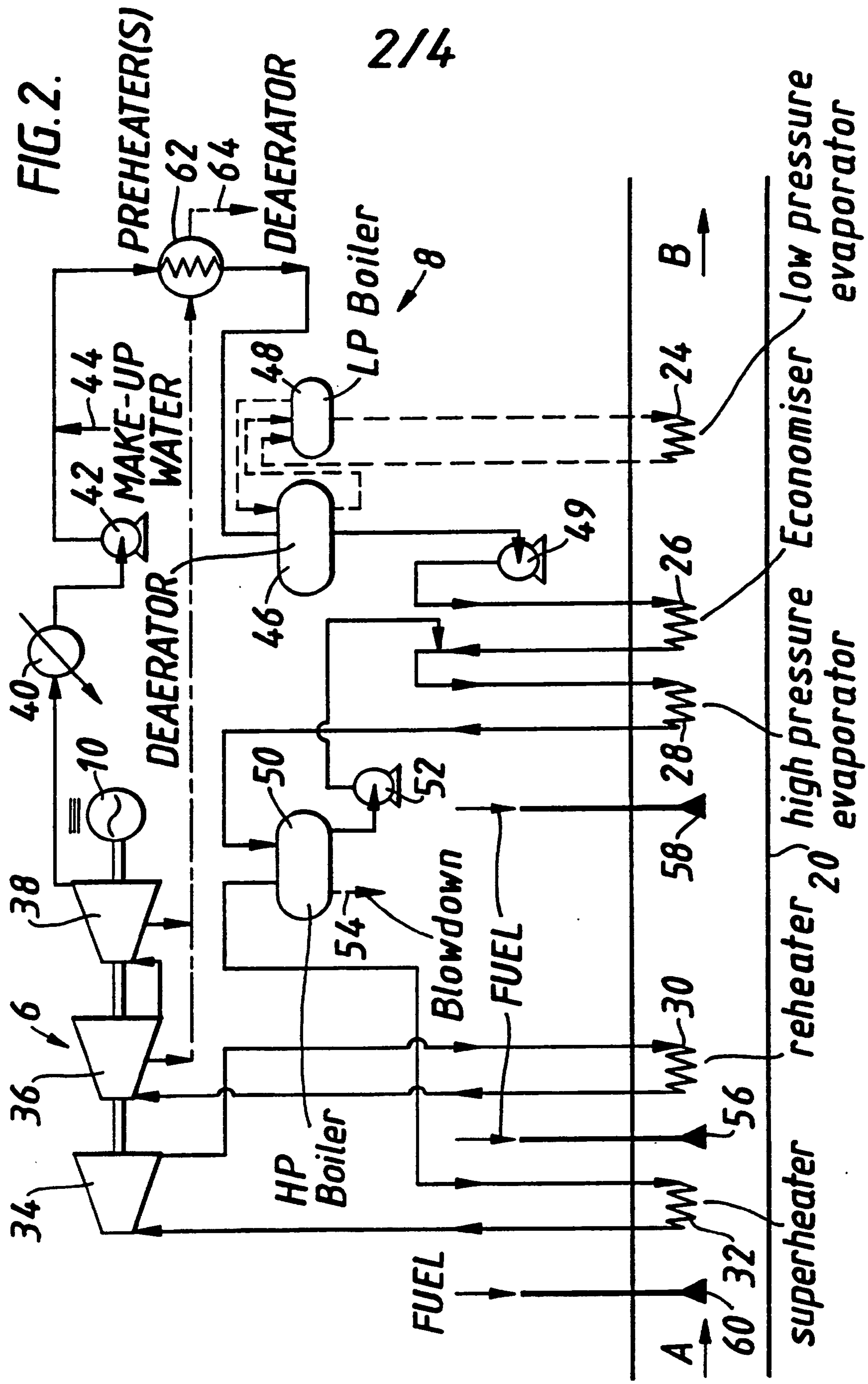
FIG.1.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DEAERATOR
LP Boiler
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Blowdown
FUEL
HP Boiler
FUEL
A
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20
superheater
reheater
high pressure evaporator
Economiser
low pressure evaporator

FIG. 2.

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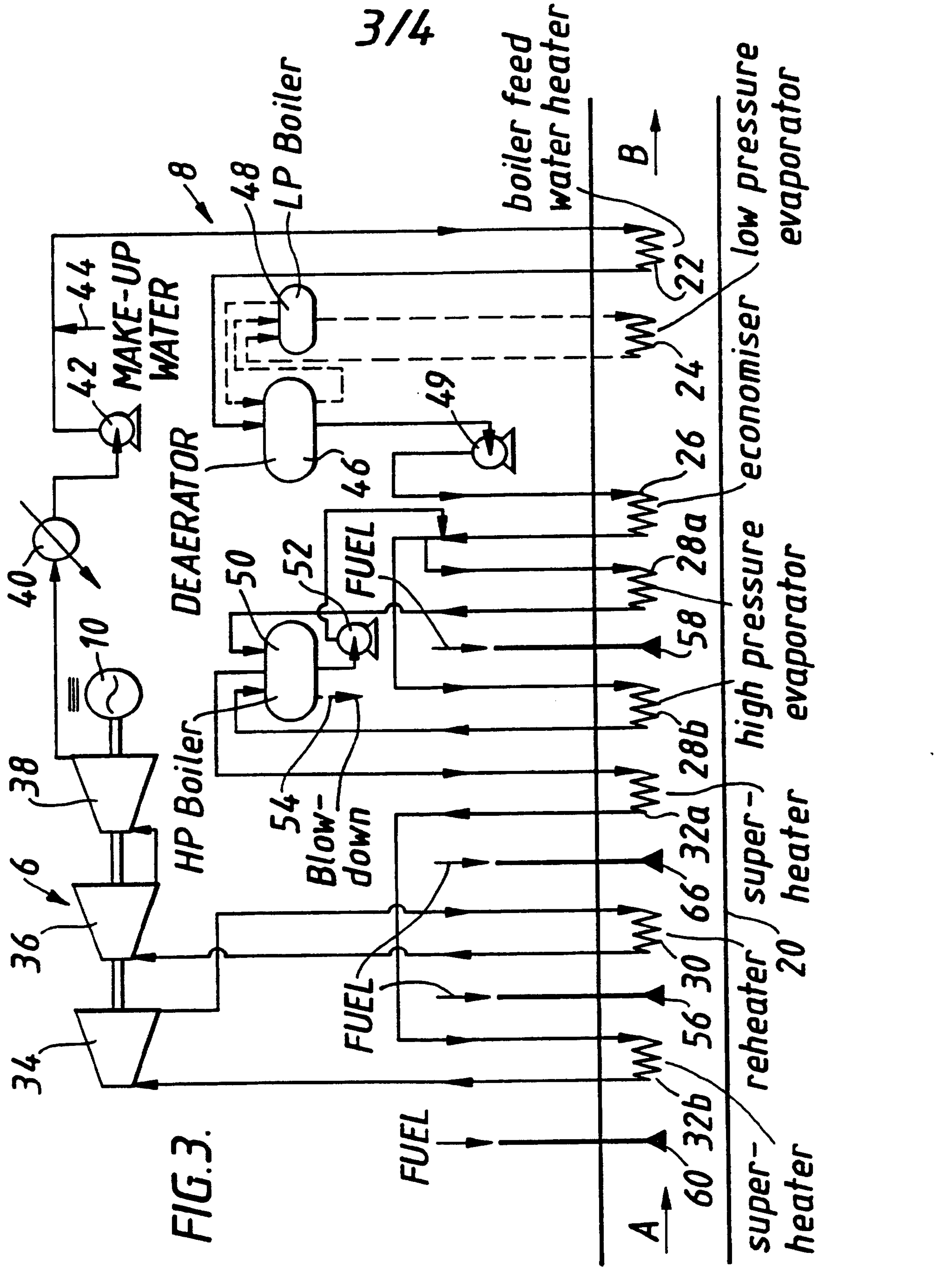
boiler feed water heater
LP Boiler
MAKE-UP WATER
DEAERATOR
FUEL
FUEL
FUEL
HP Boiler
Blow-down
low pressure evaporator
economiser
high pressure evaporator
super-heater
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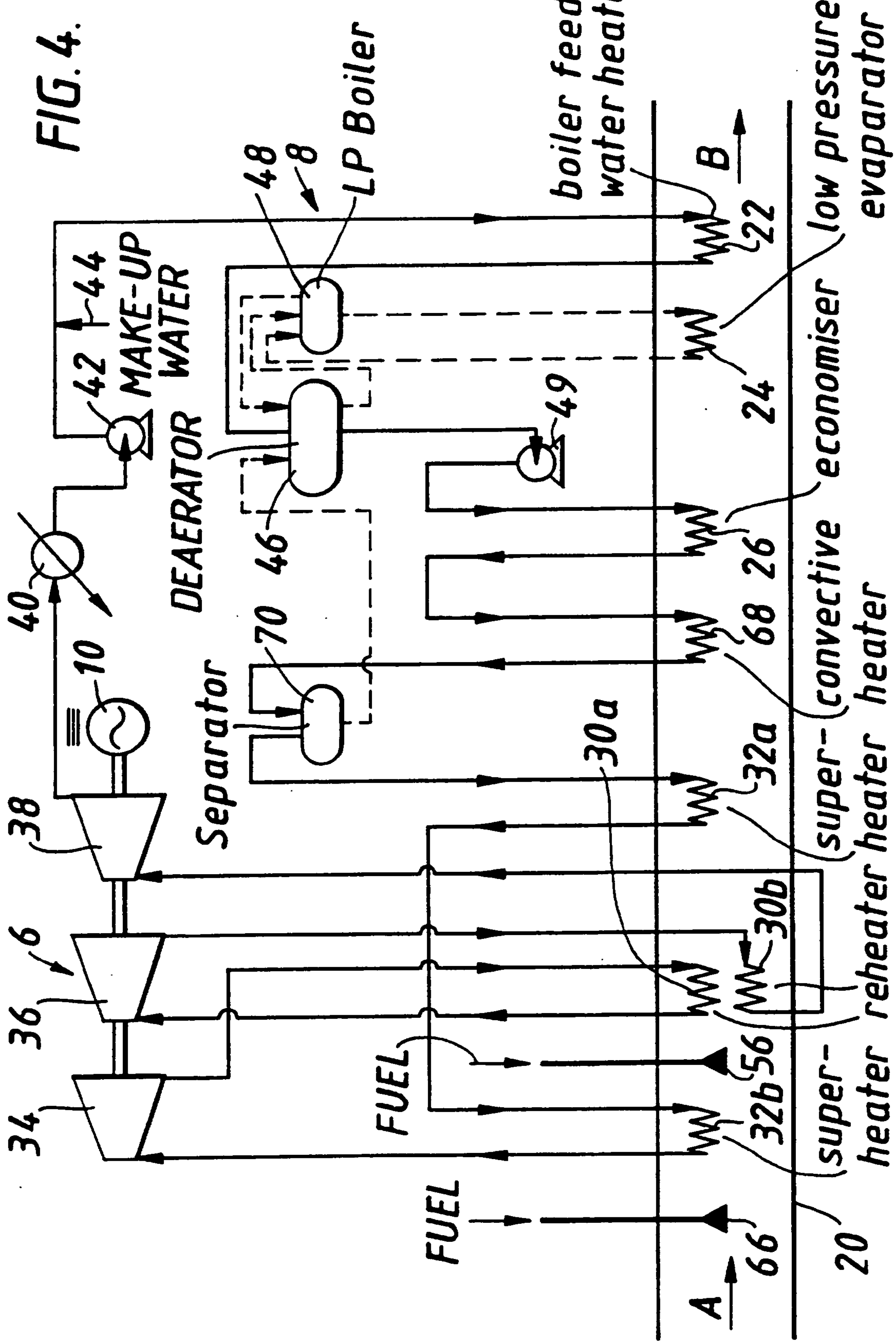
FIG.3.

4/4

FIG. 4.



LP Boiler
48
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boiler feed water heater
B
22
low pressure evaporator
24
MAKE-UP WATER
44
42
DEAERATOR
46
49
economiser
26
40
10
70
Separator
68
convective heater
30a
32a
super-heater
38
6
36
30b
reheater
56
FUEL
34
32b
super-heater
FUEL
66
A
20

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 94/01013

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 F01K23/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 F01K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE,B,10 74 326 (SIEMENS) 28 January 1960 see column 5, line 8 - line 67; figures	1
A	FR,A,2 150 248 (BABCOCK) 6 April 1973 see page 5, line 12 - page 6, line 39; figures	1
A	FR,A,2 257 786 (SULZER) 8 August 1975	
A	GB,A,683 823 (METROPOLITAN-VICKERS) 3 December 1952	
A	BE,A,857 109 (SULZER) 25 January 1978	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
4 August 1994	25.08.94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+ 31-70) 340-3016	Van Gheel, J

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INTERNATIONAL SEARCH REPORT

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Intern al Application No
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